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(54) Title of the Invention:

PROCESS FOR GENERATING ULTRAVIOLET RADIATION FROM A MICROWAVE SOURCE AND DEVICE FOR IMPLEMENTING THIS PROCESS

(57) Abstract:

The invention concerns a process for generating ultraviolet radiation from a microwave source and an electrodeless tube *9* placed in a cavity *8* excited by means of a microwave generator *1* and resonated at an appropriate mode, and is characterized by the fact that it consists in orienting the polarized stationary electric field *E* of constant amplitude parallel to the axis of the discharge tube *9*, and in overdimensioning the cavity so that this tube has its longitudinal dimension along a resonance antinode of the mode excited in the cavity.

PROCESS FOR GENERATING ULTRAVIOLET RADIATION FROM A MICROWAVE SOURCE AND DEVICE FOR IMPLEMENTING THIS PROCESS

The present invention concerns a process and a device for generating intense light radiation in the ultraviolet region, applicable in particular in the treatment of industrial products coated with a layer of ink or varnish or with a photosensitive product, in order to achieve homogeneous and uniform drying, or else for specific applications in the areas of industrial photosynthesis, surface treatments, photochemical reactions, etc.

Processes are already known which make it possible to produce ultraviolet radiation from discharge lamps equipped with electrodes connected to an appropriate source of voltage, creating ionization and intense light emission in the gas atmosphere of the lamp. These lamps are nonetheless not very practical to use, requiring very high starting voltages, and do not make it possible to obtain completely homogeneous ultraviolet radiation over a sufficient surface area for the applications in question.

Systems are also known which use a tube of a gas atmosphere sealed under a suitable pressure and without electrodes, in which the emission of an ultraviolet radiation is achieved thanks to a high-frequency electric field of constant amplitude, generated along a predetermined direction through the lamp,

whereby this field is produced from a suitable microwave source coupled to a cavity or chamber adapted for this purpose, inside which the tube is located.

But in order to obtain a homogeneous emission of ultraviolet rays over a sufficient dimension inside the tube, and in particular along the entire length of the tube, which may be as much as 20 cm or more, so that the light flux obtained hits the product to be treated along a uniform strip or region whose relative movement by moving the product creates a continuous and regular treatment over the entire surface of this latter, the electric field must be distributed in the tube by means of a traveling wave at constant amplitude, but with an intensity which is also sufficient to induce the required discharge and maintain it.

U.S. Patents No. 3,872,349 and No. 4,042,850 in the name of Fusions Systems Corporation illustrate embodiments of this type, with an electrodeless tube excited by hyperfrequency radiation, in particular between 1 and several tens of gigahertz, and preferably equal to 2,450 MHz, the standard frequency in industrial microwave applications.

These patents describe in detail the physical theory which makes possible the production of ultraviolet radiation under the effect of an electric field of constant amplitude, in which the electrons collide with the ions of the gas confined in the sealed tube, producing a suitable light emission by changing energy levels.

Nevertheless, an essential characteristic of the prior art thus represented consists in exclusively using a traveling wave through the tube, but carefully preventing any stationary wave which might result from a resonance phenomenon in the propagation of the electromagnetic wave coupled to the cavity containing this tube. In fact, in the case of such resonance with a suc-

cession of nodes and antinodes occurring along the length of the tube, with this latter positioned in the direction of the fundamental mode of the wave created, it is evident that the light energy of the ultraviolet radiation produced will mainly be emitted to the right of the areas where the electric field is maximum, thus at the antinodes, with first a decrease from these latter along the longitudinal dimension of the tube to a minimum corresponding to a node, then an increase to the next antinode, and so on. The ultraviolet radiation emitted will therefore be essentially variable along the tube length, and will not permit a homogeneous distribution over the sheet or other material to be treated, which is generally moving parallel to the tube.

To avoid such a resonance, the above-cited patents therefore specify traveling wave devices, where the hyperfrequency energy coming from appropriate emitters is coupled to the cavity and to the tube it contains by slots staggered axially and laterally, opposite to one another with respect to the direction of the discharge tube and the ends of the cavity containing it. In addition, two emitters are generally used, respectively coupled to two slots thus staggered, and their frequencies are themselves separated by a gap of about 15 MHz on either side of the average frequency of 2,450 MHz.

These known systems, widely sold today, have advantages over those using lamps with electrodes under voltage, thanks in particular to a rapid rise to temperature and to the option of almost instantaneous successive starting and extinguishing, which is particularly useful for treatments where the ultraviolet radiation must be very accurately controlled. Because of the absence of electrodes, the tube used is more luminous and can be more extensively utilized over its entire longitudinal dimension for the production of the radiation used. In addition, the simultaneous emission of infrared radiation is

reduced, thereby limiting the release of heat from the tube and noticeably increasing its useful life.

On the other hand, other drawbacks persist: in fact, these systems are limited in size and in power, since the energy supplied to the cavity and to the tube contained in it is distributed along the entire length of this tube by the traveling wave created, with definite losses overall. In addition, the coupling of the microwave energy to the tube is sometimes difficult to ensure so as to make it possible to keep a perfectly constant electric field amplitude over the entire length of the tube where the traveling wave propagates.

It is known, moreover, that in other known embodiments with a resonant structure, the propagation of an electromagnetic wave, in particular at 2,450 MHz, usually occurs in fundamental mode in a standard guide with a rectangular cross section where the short side is equal in this case to about 4.3 cm. If the electrodeless tube is placed in the axis of the guide and at its center, and if the structure is resonated, the succession of nodes and antinodes in the electric field distribution is therefore going to create, to the right of the antinodes, regions of maximum field where the emission of ultraviolet radiation will be the most intense. In these regions, the electric field component is directed in a diametral plane of the tube, perpendicular to the long sides of the guide and therefore parallel to its short sides. The result is that in this case, the ultraviolet radiation coming from the tube will be emitted over a length of only 4.3 cm, with, as described above, a succession of areas of emission and extinction along the length of the tube which are quite disadvantageous if the ultimate goal is to obtain a homogeneous distribution over an acceptable distance.

Finally, French Patent No. 82/04,398 of March 16, 1982, in the name of

the CNRS (National Center for Scientific Research) discloses a process and a device for the direct microwave treatment of sheet products, which consist in using microwave applicators in the form of elongated resonant cavities where electric field distribution is achieved with a succession of nodes and anti-nodes along the main axis of each applicator. These have a prismatic shape, in particular with a rectangular cross section, where the dimension of this cross section parallel to the electric field is adjusted to approach the TE012 mode resonance conditions, and has for this purpose a dimension at least greater than double the other side of the same cross section.

According to the information of this French patent, we thus learn that compared to a standard guide with a rectangular cross section, where the side perpendicular to the direction of the electric field is close to 8.6 cm and the side which is parallel is 4.3. cm, we can give this latter dimension a much higher value, which may be between 8 and 10 cm, and preferably is 9.1 cm. It has since been found that this same dimension can be increased up to 20 or even 25 cm, without altering the resonance conditions in the guide for the mode in question.

The object of the present invention is a process and a device which, by implementing the above specifications, avoids the limitations of traveling wave systems of the type reviewed above, making it possible, for a given energy applied to the cavity containing the electrodeless tube, to supply a higher-powered ultraviolet radiation using stationary waves in a resonant structure in accordance with the instructions of the above-mentioned French patent, with adaptation of these latter to the new application more specifically intended.

Moreover, the invention aims to provide a system where the coupling of

the hyperfrequency field to the electrodeless tube is more efficient, while making use of a simpler production technique which requires only one means for tuning the resonance frequency in the cavity receiving the tube and produces overall a more reliable, less cumbersome, and above all less expensive device than with the prior solutions, in particular the traveling wave designs.

For this purpose, the process according to the invention, using an electrodeless tube placed in a cavity excited by at least one microwave generator and resonated at an appropriate mode, is characterized by the fact that it consists in orienting the polarized stationary electric field at constant amplitude parallel to the axis of the discharge tube, and in overdimensioning the cavity so that the tube has its longitudinal dimension along a resonance antinode of the mode excited in the cavity.

The invention consists, in other words, of a new application of the process known by the above-mentioned French patent, by adapting to it the known method consisting of an electrodeless tube containing a plasma and having a flow of polarized electrons act on it, defining the electric field component of a hyperfrequency radiation supplied by a microwave generator. The collisions on the ion atoms of the gas in the tube cause the emission of light radiation, in particular in the ultraviolet region. The specified application uses an overdimensioned resonance structure, so that the tube extends along a resonance antinode and is thus excited over its entire longitudinal dimension, permitting a significant increase in the overall energy yield of the structure.

The device for implementing the process is characterized by the fact that it consists of a resonant cavity, at least one microwave emitter feeding into this cavity, a means of coupling between the cavity and the emitter, a device

for adjusting the frequency tuning of the cavity, and an electrodeless tube containing a gas at a given pressure, placed in the cavity along the direction of the electric field component for the excited mode, whereby the cavity is overdimensioned so that said component has a resonance antinode along the length of the tube.

In a first variant of the device under consideration, the cavity is prismatic and has a rectangular cross section to allow excitation of the TE012 mode of the hyperfrequency radiation, whereby the tube is placed along the zero-order direction of the mode.

In another variant, the cavity is cylindrical, with a partially elliptical cross section, whereby the tube is placed along one of the foci of the cavity. Preferably, this latter has a polished reflecting wall making it possible to focus the ultraviolet radiation emitted by the tube at the other focus of the cavity, excited on the TM010 mode of the hyperfrequency radiation.

According to another particular characteristic of the invention, the cavity has an open side parallel to the tube and consisting of a fine mesh transparent to the ultraviolet radiation emitted by the tube and opaque to the hyperfrequency radiation.

Advantageously, the device has two microwave emitters of identical or very similar frequency, with the difference in frequencies being less than the passband of the resonant cavity, so that the effects of each emitter are additive.

Also preferably, the frequency of the microwave radiation is 2,450 MHz, whereby the tube mounted in the cavity has a length of at least 20 cm.

In still another variant, the microwave emitters can have a variable

power and excite the resonant cavity by means of an insulator which absorbs the wave reflected by the cavity while protecting the emitters. The wave reflected by the resonant cavity, in particular during transitory excitation conditions, is advantageously absorbed by a traditional water load.

Other characteristics of the process and the device according to the invention will become evident from the description which follows of two embodiment examples, given as a guideline and nonlimiting, with reference to the attached drawings, in which:

– Figure 1 is a schematic drawing of the device according to the invention; and

– Figures 2 and 3 are perspective views of two respective variants of the resonant cavity containing the electrodeless tube, for the emission of ultraviolet radiation.

In the diagram in Figure 1, *1* indicates a microwave generator of suitable power, but generally chosen as 1,200 W under nominal conditions. This generator is excited by a modulator *2* and delivers a hyperfrequency radiation into an adjusted guide *3* connected to an insulator *4*, which is itself coupled by another guide *5* to a water load *6*. The radiation usually has a frequency of 2,450 MHz.

The insulator is also connected by a third guide *7* to an appropriate coupling means (of the iris or half-wave antenna type) with a resonant cavity *8*. Over most or all of it, this latter contains an electrodeless tube *9* containing a pressurized gas and such that the effect of the electric field *E* component *10* created in the cavity *8* by the radiation from the emitter produces an emission of ultraviolet radiation, indicated in the figure by the wavy arrows, extending in a plane passing through the axis of the tube and perpendicular to

the short side of the cavity. A harmonizer *11* makes it possible to adjust the frequency in the cavity *8* if necessary, and in particular to bring it to the resonance according to an appropriate mode, so that an electric field antinode develops along the longitudinal dimension of the tube *9* which is equal to 20 or even 25 cm, thus permitting homogeneous and regularly distributed emission of the ultraviolet radiation.

In the example illustrated in Figure 2, the resonant cavity *8* containing the tube *9* has a prismatic form with a rectangular cross section; its long side *a* corresponds to a zero-order TE012 mode, parallel to the component *10* of the electric field *E*, and the sides *b* and c off the cross section correspond to orders 1 and 2 of the above mode. The guide *7* through which the microwave radiation is fed to the cavity *8* has an appropriate coupling slot *12*. In addition, opposite the guide *7* the cavity *8* has an open face *13*, in the plane of which there is a fine mesh *14* which allows the microwave radiation from the tube *9* to pass through along the arrows *15* with little alteration but prevents the escape of the hyperfrequency radiation from the cavity, where it thus remains confined.

The ultraviolet radiation thus produced homogeneously over the entire length of the tube *9* along the length of the tube *9* delimits a continuous strip *16* of the same size on a material *17* to be treated, which can be moved along the direction of the arrow *18* by any appropriate means (not shown) to allow a complete treatment of the entire surface, for example to dry a layer of ink or vanish coating it.

Figure 3 illustrates another variant of the cavity *8*, in which it is in the form of a chamber with a partially elliptical cross section. The inside wall *19* of the cavity *8* is preferably made of a material which is reflecting

for the ultraviolet radiation produced. Here the tube *9* is placed parallel to an axis of the chamber at one of the foci of the corresponding ellipse. The strip *16* formed on the sheet of material *17* in the region where the ultraviolet radiation is concentrated is positioned at the second focus of the same ellipse. In this variant, the opening *13* is covered by the mesh *14* to allow confinement of the hyperfrequency radiation but escape of the ultraviolet rays, as in the preceding example.

Thus a source of radiation is obtained which is perfectly suited to the treatments under consideration. It is simple in design and noticeably lower in cost than the solutions known in the art, requiring a greatly reduced microwave energy for a given supplied power. Nevertheless, it must be understood that the invention is not limited to the examples described, but encompasses all the variants within the scope of the man of the art.